Effect of Temperature on Wear Rate of Si-Epoxy-Eglass Polymer composite Materials

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***Abstract*— With the increase use of polymer composites in erosive work environment, it has become extremely important to investigate their erosion characteristics. The hybrid composite consisting of a Epoxy resin reinforced with Eglass fiber and Si particles was developed. The effect of temperature on wear rate applied to Si – Epoxy – Eglass polymer composite has been studied. It has been found that the wear rate increases as the temperature of carrier media (air) is increased. Temperature of carrier media is one of the significant factor influencing the erosion wear. The results were compared with the plain epoxy composite material. Micrographs of eroded surface are also presented to study the wear rate and Wear behavior of composite.**

***Keywords*—Solid particle erosion, polymer-matrix composite, wear testing, electron microscopy.**

I. Introduction

Fibre reinforcement affects the strength, ductility, thermal conductivity and creep resistance of composite and the failure mechanism. Fibre volume fraction, orientation, aspect ratio and fibre/matrix interface strength also influence the failure morphology. Apart from these, gating system, mould geometry and melt temperature, affect the morphological features such as Fibre orientation and Crystallinity and hence the failure mechanism [1, 2, 3].

R. Rattan, Jayashree Bijwe [4], Polyetherimide (PEI) composite reinforced with plain weave carbon fabric (CF) (40% by volume) was developed and characterized for physical and mechanical properties. The erosive wear behaviour of PEI and its composite was evaluated using silica sand particles at a constant impact velocity by varying angles of impingement. It is confirmed that though all the mechanical properties of PEI improved substantially by CF reinforcement, the erosion resistance (WR) is deteriorated by a factor of almost 4 to 6 times at all angles of impingement.

The solid particle erosion behaviour of fiber and particulate filled polymer composites has been reviewed by Amar Patnaik et al [5]. An overview of the problem of solid particle erosion is given with respect to the processes and modes during erosion with a focus on polymer matrix composites. The new aspects in the experimental studies of erosion of fiber and particulate filled polymer composites are emphasized in this paper. Various predictions and models proposed to describe the erosion rate are listed and their suitability was mentioned.

G. Amirthan etal [6], conducted Solid particle erosion tests on four different types of silicon carbide ceramic composites. The composites are cotton fabric based Si/SiC with and without chemical vapour infiltration, fine teak wood powder based Si/SiC and coarse teak wood powder based Si/SiC. Scanning electron microscopic observations on the eroded surface show brittle and cleavage like fracture. Fine teak wood powder based Si/SiC ceramic showed better erosion resistance than the other ceramics. Homogenous distribution of SiC grains with the presence of very fine grains of silicon and carbon has proved responsible for the improved erosion resistance. The higher erosion rate in cotton fabric based SiC has arisen from its microstructure. Here, the free Carbon and free Silicon grains are large in size and the SiC phase had a very low hardness as compared to the erodent.

The investigator [7], reported that reinforcement fiber such as carbon fiber (CF) and glass fiber (GF) can enhance the strength of polymer composites, but reduce the particle erosion resistance of the polymer composites. In the study, organic high-polymer fibers (Dyneema® and Zylon®) are used as reinforcement to make fiber-reinforced polymers (FRPs). The damaged surfaces of the Dyneema-fiberreinforced polymer (DFRP) and Zylon-fiber-reinforced polymer (ZFRP) were analyzed with a scanning electron microscope, and the erosion wear mechanisms of the composites are discussed. It was concluded that it was feasible to develop the FRP materials with low density, high strength, and excellent particle erosion resistance.

Use of inorganic fillers in composites is increasing. Fillers not only reduce the cost of composites, but also frequently impart performance improvements that might not otherwise be achieved by the reinforcement and resin ingredients alone. Filled resins shrink less than unfilled resins, thereby improving the dimensional control of molded parts. Important properties, including water resistance, weathering, surface smoothness, stiffness, dimensional stability and temperature resistance, can all be improved through the proper use of fillers. The thermosetting resin segment of the composite industry has taken advantage of the properties of fillers for many years. More recently, the thermoplastic industry has begun to make widespread use of inorganic fillers. Breakthroughs in chemical treatment of fillers that can provide higher filler loadings and improved laminate performance are accelerating this trend.

In this paper, an attempt has been made to develop Si particle filled Eglass Epoxy composite material and study is

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carried out to identify the erosive wear with hot air as a carrier media for erodent. The effect of temperature wear rate on this composite material has been discussed and the morphology of eroded surface is analyzed using micrographs.

II. Materials

Hybrid composite material developed consists of 900 orientation Woven E-glass fiber of 400gsm is used as the common reinforcement. Low temperature General purpose epoxy resign LY556 in combination with hardener is used as a matrix material. Silicon powder which is commercially available is used as a filler material. As silicon is the most cost effective and widely used material and with an excellent combination of properties and a reasonable price, the fine grain technical grade Silicon powder has a wide range of applications. This potential made it to be used as a filler material in various polymer matrices. It is used in refractories and in numerous high-performance applications. Moreover, they have low density, low thermal expansion, high elastic modulus, high strength, high hardness and superior chemical inertness.

II. Composite fabrication

The hybrid laminates used for the study are processed by open mould hand lay-up with Compression process. 900 orientation woven E-glass fibers are reinforced in GP resign with particulate fillers of varying weigh percentage to prepare the composite. The same method is employed to prepare the plain composite specimen. The castings are put under the load for about 24 hours for proper curing at room temperature. Specimens of suitable dimensions are cut for physical characterization and erosion test. The fillers are mixed thoroughly in the GP resign before the woven glass fiber mats are reinforced in the matrix body. Composites contain Silicon particles in 10wt% and Matrix is 40wt% proportion, respectively. The entire composite contains 50wt% of woven E-glass fibers in them.

III. Experimentation

The schematic diagram of experimental test rig to study the wear rate of composite as shown in Fig.1. It consists of portable Abrasive chamber (Mecshot blasting equipment Ltd., India), Heating chamber with controller (Heat process Ltd.India), Mixing head, Nozzle and Two axis table with CNC controller. A part of air flows through the abrasive chamber. Feeding of abrasive particles takes place due to the pressure difference in the abrasive chamber and main flow. Abrasive particles are mixed with air and then they enters into the mixing head where the hot air mixed with abrasives and then passed through the nozzle. The abrasive hot jet is available at the tip of nozzle striking on the target. The flow of abrasive is controlled by a valve below the chamber.

The nozzles are usually made up of Sapphire / tungsten material of hardness 50-60 HRC. As the tungsten carbide material is of high cost, in this research work, alloy steel

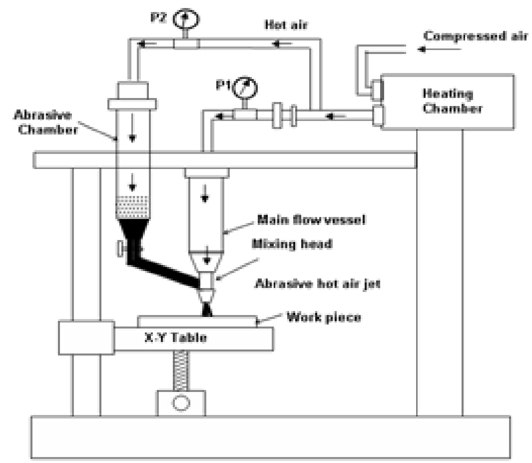

Figure 1. Schematic diagram of Experimental setup

(EN38) heat treated of hardness 50 HRC is used for nozzles. In the present work, Si – Epoxy – Eglass polymer Composite is used as the work material. The suitable size of specimen is used for the processes. The temperature of air at the exit of nozzle is measured using sensors (Thermocouples). The process parameters for erosion test on Si– Epoxy– Eglass polymer Composite are specified in Table 1.

Table I. Process parameters

Parameters	Condition
Jet Pressure	0.25 Mpa
Abrasive material	Silica sand, SiC
Abrasive grain size	100 μm - 150 μm
Nozzle diameter	3 mm
Abrasive flow rate	16 g / min
Stand off distance	12 mm
Air temperature	27°C - 310°C

In this process, a large number of process variable are involved and all these variables affect the erosion results directly and indirectly. For the purpose of present investigation, only major and easy to control variables like stand-off distance, air temperature and time are considered in this experiment. The other experimental parameters are kept constant throughout the machining process as shown in Table 1. After the test, the samples are cleaned with pressurized air and weight loss is measured using a digital electronic balance (BSA224S-CW, SARTORIOUS, GERMANY) with resolution of 0.1mg. Four measurements for each sample are taken and the average value is the final reading.

IV. Result and discussion

A. Influence of Air Temperature on Wear Rate

Experiments are conducted on Plain Epoxy composite and Si – Epoxy – Eglass polymer Composite Materials at different temperatures of air and under normal impact condition while keeping other parameters like abrasive flow rate, feed rate,

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velocity of air with abrasive, diameter of nozzle, thickness of work material are remains constant. The effect of air temperature on Wear rate is studied for two different abrasives like silica sand (Sio2) and silicon carbide(SiC) of size 100µm and 150µm respectively. The results are plotted as shown in Fig.2. and Fig.3 .

It is clear from Fig.2. that the air temperature has more significant effect on the Wear rate at temperature above 100^o C. It can be found that Wear rate at higher temperature is about 1.4 to 1.6 times more than that at low (room) temperature. The same trend is seen when SiC is used as abrasive and the overall Wear rate is more as compared to silica sand. Moreover, the increase of abrasive size increases the Wear rate as shown in Fig.3 and Fig. 4. It is further observed that the Wear rate is highest at 310^{o}C for 150 µm of abrasive. The results indicate that the temperature of air is also an important factor in the machining process.

As hot air is supplied on the target, the temperature of target is increased resulting in increasing the size of radial crack initiated by impact of abrasive material. It helps in removal of larger size of chips from the work material. In agreement with this, our study reveals that the Erosion rate of material at high temperature is more as compared to that at low temperature. There is an evidence of crack initiation taking place by brittle nature at low temperature. As the temperature increases,deep chipping followed by plastic deformation is observed. Hence,erosion rate increases and thus the hot air has its influence in increasing Wear rate.

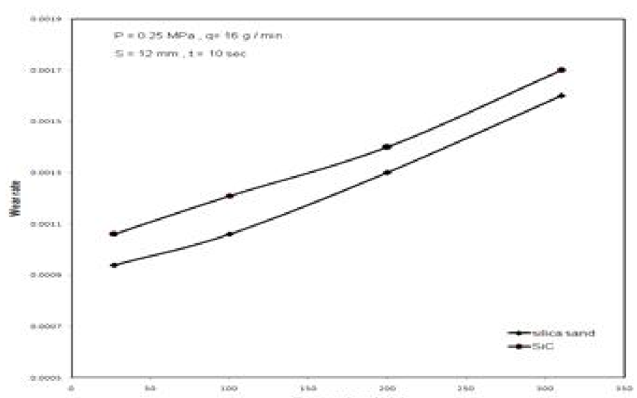

Figure 2.Variation of wear rate with air temperature for 100 µm abrasives Silica sand and SiC

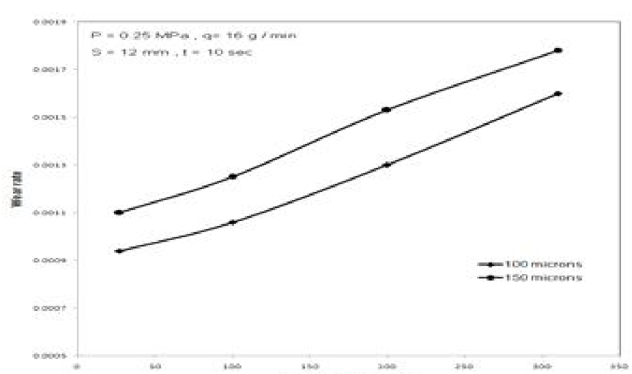

Figure 3. Variation of wear rate with temperature of for different grain size (Sand)

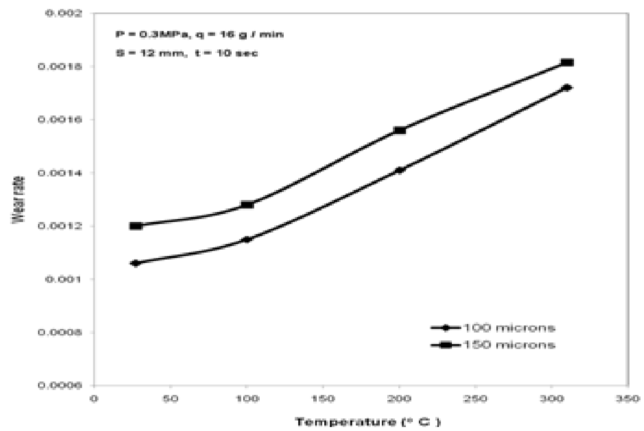

Figure 4. Variation of wear rate with temperature of for different grain size (Silicon Carbide)

From fig. 5 it can be noticed that the erosion rate is higher in plain Epoxy composite due to the less harness as compared to Si-Epoxy-Eglass under the same machining parameters as above. Debonding of material takes place at the lower temperature in plain Epoxy composite material which influence in large sized chipping and thus causing the increase in wear rate.

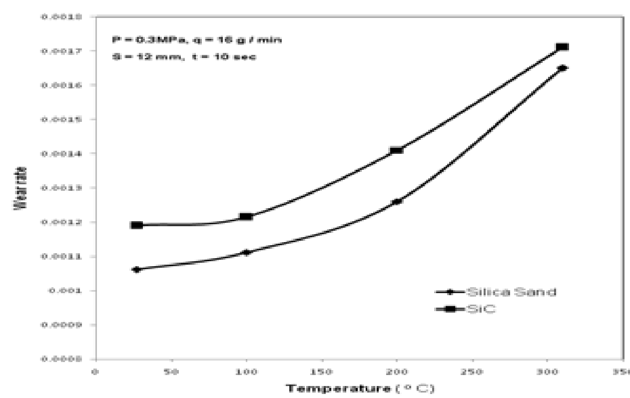

Figure 5. Variation of wear rate with temperature of for different grain size (silicon carbide)

B. SEM Study

The micrographs of the eroded surface of Si – Epoxy – Eglass polymer Composite samples at two different temperatures (27^{o}C and 310^{o}C) using abrasive particles of size 100µm are shown in Fig.6 and Fig.7 respectively. There are many differences between the micro features of two cases. The morphology of the surface eroded at low temperature of air is typical due to the brittle failure . The matrix layer is eroded and there is no presence of crack on glass fiber as shown by arrow mark in Fig.6. The matrix is chipped off and the glass fibers are Clearly visible beneath the matrix layer.
Particle impingement produces a rise in temperature of the surface of material which makes the matrix deformation easy because the high temperature that occur in solid particle erosion invariably soften the matrix. On impact of the erodent particle, kinetic energy is transferred to the composite body that leads to crater formation and subsequent material loss. The features corresponding to 310^{o}C indicate growth of crack material is removed by chipping, that results in increase of

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erosion. The plastic deformation as well as brittle failure has seemed to found at this temperature as shown in Fig. 7. The erodent particle penetrated deeply into the substrate, shows an erosion pit formed by an impacted particle which is surrounded by the material deformed plastically. The details of plastic deformation can be seen in Fig. 6. where particle cut deeply into the substrate produces a groove which is pulled out the glass fiber as indicated by arrow mark. Due to the repeated impact of hard and high temperature sand particles, there is an initiation of Cracks on the fibers and as erosion progresses, these cracks randomly propagate on the fiber bodies both in transverse as well as longitudinal direction. Such transverse cracks are clearly noticed in Fig. 7. It has an influence to increase the rate of erosion.

From Fig. 6 and Fig.7, it can be found that the morphology of material eroded at high temperature provides sufficient evidence of plastic deformation by brittle fracture failure. There is an evidence that at room temperature, erosion takes place due to brittle fracture only where as at high temperature, both brittle and plastic deformation takes place. In agreement to this, Wear rate is more at high temperature as compared to that at room temperature.

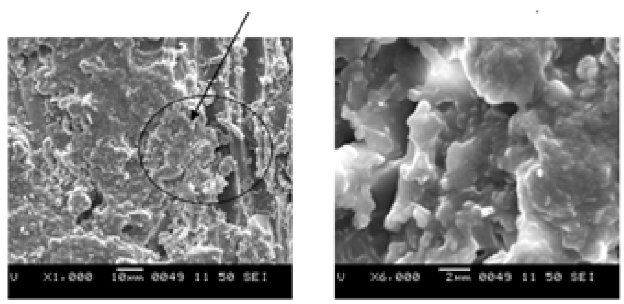

Figure 6. SEM of the specimens at room temperature

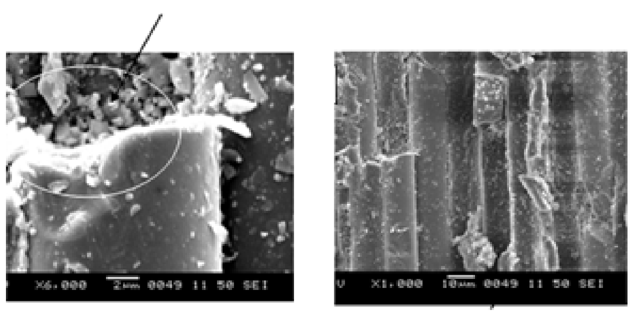

Figure 7. SEM of the specimens at High temperature (320 ^{0}C)

Conclusions

The effects of air temperature on Wear rate of machined surface are studied in this paper. From the experimental investigation, the following conclusions are derived. It has been found that the mechanical properties are altered with increase of temperature which lead to the increased penetration rate of particles, surface damage, enhanced crack growth etc., The effect of air temperature on wear rate is more significant above at high temperature. The wear rate increases as the temperature of air is increased. The morphology of eroded surface indicates that at low temperature, brittle failure takes place. It is found that at high temperatures, there is sufficient evidence of plastic deformation accompanied by brittle fracture failure which results in increasing of erosion rate. The study reviles that Si particles influence in resisting the wear rate by increasing the hardness of the composite material.

References

[1] Lee Y and Porter R.S “Crystallization of PEEK in carbon fibre composites”, Polymer Engineering Science, vol.26, PP. 633-639, 1986.

[2] Cirino M, Friedrich K and Pipes R.B, “The effect of fibre orientation on the abrasive wear behaviour of polymer composite materials”, Wear, Butterworth and Co. Ltd, Vol 19(85), PP.127-141, 1988.

[3] Dominick V.R, Donald V.R and Marlene G.R, “ Design influencing factors”, Olastic Design Handbook, Kluner academic publications, PP.45-85,2000.

[4] R. Rattan, Jayashree Bijwe ,”Influence of impingement angle on solid particle erosion of carbon fabric reinforced polyetherimide composite “ ,Wear 262 (2007) 568–574.

[5] Amar Patnaik, Alok Satapathy, Navin Chand, N.M. Barkoula, Sandhyarani Biswas ,”Solid particle erosion wear characteristics of fiber and particulate filled polymer Composites: A review”, Wear 268 (2010) 249–263.

[6] G. Amirthan, A. Udayakumar, V.V. Bhanu Prasad, M. Balasubramanian “, Solid particle erosion studies on biomorphic Si/SiC ceramic composites”, Wear 268 (2010) 145–152.

Letter, “Fiber-reinforced polymer composite materials with high specific strength and excellent solid particle erosion resistance”, Wear 268 (2010) 637–642.

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